Section 11

Carbon Balance of Peatlands at Moor House

Table of Contents

11. Carbon balance of Peatlands at Moor House

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11.1. Introduction

Upland peats represent the largest store of carbon in UK ecosystems. Carbon balance of these peatlands will be affected by changes in land use (particularly grazing pressure and management for grouse) as well as changes in climate, CO_2 concentration and nitrogen deposition. These peatlands have the potential to act as a major source or sink for carbon if they are degrading or agrading, but their current status is unknown. This work will quantify the carbon balance of an upland peat catchment at Moor House, Teesdale, typical of much of upland peat areas in the UK. Whilst some previous studies have measured the net atmospheric exchange of carbon over peatland sites, the results cannot be easily interpreted as the complete carbon balance, as a substantial fraction may be lost through stream water (as dissolved and particulate organic carbon (DOC and POC), dissolved inorganic carbon (DIC), dissolved gases, as well as fluxes of gases from stream water (evasion)). The unique aspect of this work will be to measure all components of the carbon budget, including atmospheric and fluvial fluxes, at a site where long-term records are available.

Predicting changes in the store of carbon within the soil resulting from changes in land use or climate requires a process-based model. Historically, such models have been developed for conditions typically encountered in intensive agricultural systems, such as arable crops and improved pasture, where mineral soils predominate. However, much of the soil carbon within the UK is found in highly organic soils, in upland areas where land management is minimal, and the climate is cool and wet. Existing soil models (such as RothC) fail to capture the dynamics of carbon in these highly organic soils, largely because of differences in soil chemistry, soil fauna and microbial community composition**.** Basic measurements of the model parameters (turnover rates, pool sizes) and variables (carbon fluxes in, out & between pool) necessary for validation are lacking. Here, we aim to make the field measurements required for developing and validating a process-based model of carbon dynamics under these conditions.

The atmospheric component of the budget will be obtained by measuring the net exchange of CO_2 by eddy covariance, with a flux footprint covering ~1 km. The fluvial components will be obtained by measuring stream water concentrations of DOC, POC and DIC together with discharge rates, in collaboration with the Environmental Change Network, CEH Lancaster. Evasion of gases from stream water is currently being investigated by Dr Mike Billett, CEH Edinburgh. The fluxes of CO_2 and CH_4 from both vegetated peat will be measured using chamber methods. These chamber methods can also be used to do manipulative experiments, deriving responses to light, temperature, soil moisture, and to investigate spatial heterogeneity related to recovery from burning of patches for grouse management. The following inputs and outputs to the system will be quantified, at varying time resolutions, over a two-year period:

Inputs:

- CO2 uptake from the atmosphere by plant photosynthesis;
- input of DOC and inorganic carbon in precipitation;

Outputs:

- efflux of CO_2 to the atmosphere resulting from plant and soil respiration;
- fluvial outputs of DOC, POC, DIC and dissolved gases;
- efflux of CH_4 to the atmosphere resulting from methanogenic microbial activity.

These measurements will be integrated to construct a complete carbon budget over the two -year period. Mechanistic modelling based on these measurements and the existing records will be used to predict the longer term changes in carbon storage within this catchment. The Moor House site is part of the Environmental Change Network, and many long-term monitoring studies have been made on the catchment since the International Biological Programme in the 1970s, and as a flagship site of TIGER in the 1990s. Long-term records are available for meteorology, hydrology, stream water chemistry and vegetation. These will be used to extrapolate estimates of the carbon balance over several decades.

11.2. Methods

11.2.1. Field site

The site chosen for the study is at Moor House in the North Penines (grid reference NY745335, altitude of 580 m, Figure 11-1). This site lies within the Moor House - Upper Teesdale National Nature Reserve, which is also a UNESCO Biosphere Reserve and a European Special Protection Area. The site is an area of extensive blanket peatland and upland grasslands. The land is owned by English Nature, and provides free range common grazing (mainly sheep) for villages in the Eden Valley. Research has been undertaken on the site since the 1930s by Universities and Institutes. A wide range of issues have been previously been investigated, especially the impact of land use change, climate change and the deposition of pollutants, and the functional processes of blanket peatland and streams. In the 1960s and 1970s the area was intensively studied as part of the International Biological Programme and in the 1990s as a flagship site of the Terrestrial Initiative in Global Environmental Research (TIGER). Further background information is available at http://www.ecn.ac.uk/sites/moorh.html. The site was chosen because of the large body data from historical and ongoing research, the co-operative land owner, and the fact that the area is typical of much of upland peat areas in the UK. The particular location for the flux tower was chosen as a good compromise between suitably level topography, representativeness of the vegetation, and vehicle access (Figure 11-2).

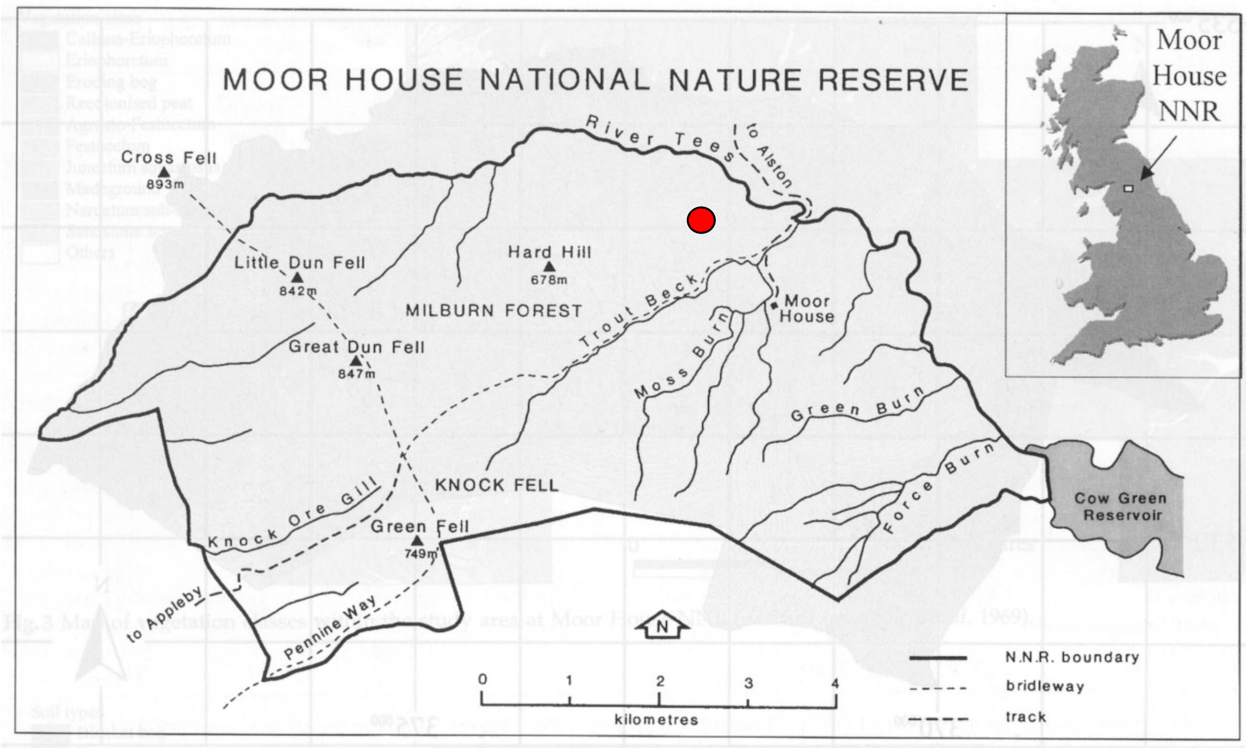

Figure 11-1 Location of the Moor House National Nature Reserve within the UK (inset) and location of the eddy covariance measurement tower within the reserve (red circle).

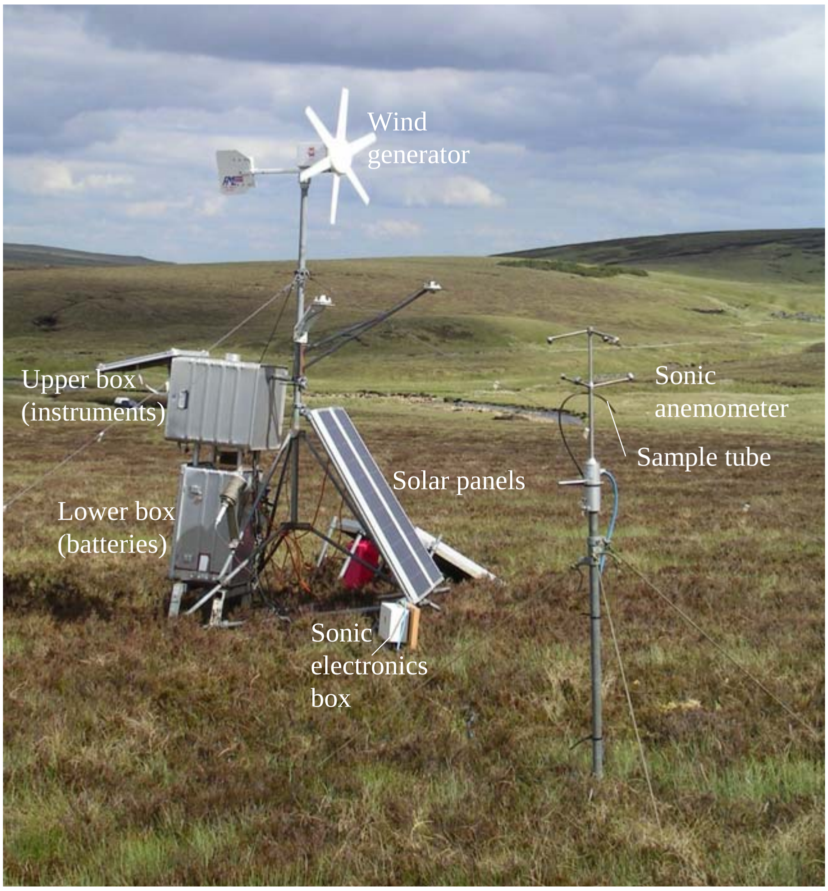

Figure 11-2 Eddy covariance equipment at the Moor House site, looking south-east.

11.2.2. Eddy covariance measurements

A micrometeorological approach, eddy covariance, is used to make near-continuous measurements of the surface exchange of carbon dioxide (CO_2) over the site. Equipment was installed between 17-25 June 2004. The eddy covariance flux measurement system was sited to the north of Trout Beck and the east of Hard Hill, on a gently sloping area of blanket peat (Figure 11-2). With the prevailing south-westerly wind direction measurements are made over one of the ECN soil sampling areas, where soil carbon is measured every five years. Full details of the instrumental techniques are as in Hargreaves *et al.*, 1998 and Hargreaves *et al.*, 2003. In brief, the net flux of CO_2, F_c, is given by:

$$F_c = \overline{w'\chi} \qquad \text{eq 11-1}$$

where w' is the instantaneous deviation of the vertical windspeed from the mean, and χ is the instantaneous deviation of the CO_2 concentration from the mean. The three components of windspeed are measured at 20 Hz by a Metek ultrasonic anemometer (Model USA1, METEK GmbH, Elmshorn, Germany), mounted at a height of 1.75 m. Air is sampled continuously from a point close to the anemometer down stainless steel tubing (0.25 inch diameter, Dekeron Corp. Illinois, USA) at a flow rate of 5 l /min. CO_2 and H_2O concentrations are measured by an infra-red gas analyser (IRGA)(LI-6262, Licor Corp., Nebraska, USA) with a response time 6.3 Hz. Analogue outputs from the IRGA are passed to the ultrasonic anemometer where they are digitised. A laptop PC, running a LabView software package, logs the data from these instruments and carries out the eddy covariance calculations.

A Campbell 23X datalogger controls switching of the power supply, and provides remote telemetry via the mobile telephone network. Supporting meteorological measurements include solar radiation, photosynthetically active radiation (PAR), soil and air temperature, relative humidity, soil moisture, and rainfall. Power is supplied by a Rutland model 910-3 Furlmatic wind turbine and four 60W solar panels with a total area of 2 m^2. These charge an array of deep-cycle sealed lead-acid batteries with a total capacity of 700 Ah. The 23X datalogger controls power consumption by switching off sample pumps and the Licor gas analyser when battery voltage is too low. Otherwise the system has been kept running from June 2004 to date, with breaks for instrument maintenance or lack of power.

In order to produce an estimate of the long-term carbon balance, gaps in the measurement data are filled using standard methodology (Aubinet *et al.*, 2000). This involves fitting simple models based on light and temperature responses to the measurement data, and using the fitted models to interpolate the missing values. For daytime values over the control area, data are fitted to the following model:

$$F_{NEE} = F_{RE_{DAY}} - F_{GPP_{OPT}}\left(1 - \exp\left[\frac{a'S_t}{F_{GPP_{OPT}}}\right]\right) \qquad \text{eq 11-2}$$

where F_{NEE} is the net ecosystem exchange of CO_2 ,F_{REDay} is the daytime ecosystem respiration rate, F_{GPPopt} is the gross primary production, S_t is the solar radiation flux and a' is a fitted parameter. Night-time fluxes are fitted to the model:

$$F_{NEE} = d\exp(eT_a) \qquad \text{eq 11-3}$$

where d is a fitted parameter and T_a is air or soil temperature. Where linear regression gives a better fit to the data, this is used instead.

11.3. Results and Discussion

Figure 11-3 shows the response of the CO_2 flux to photosynthetic photon flux density (ie. 'light') in mid-summer 2004. This shows the typical form of response, with a near-linear increase in the flux up to around 400 µmol m-2 s-1 PPFD, and reaching saturation at around 1000 µmol m-2 s-1 PPFD. The net fluxes are relatively low compared with forest and agricultural ecosystems, where maximum fluxes are commonly in the range 10 to 20 µmol m-2 s-1. This is probably because of the lower LAI, the mature state of the vegetation, and the environmental limitations imposed at the site.

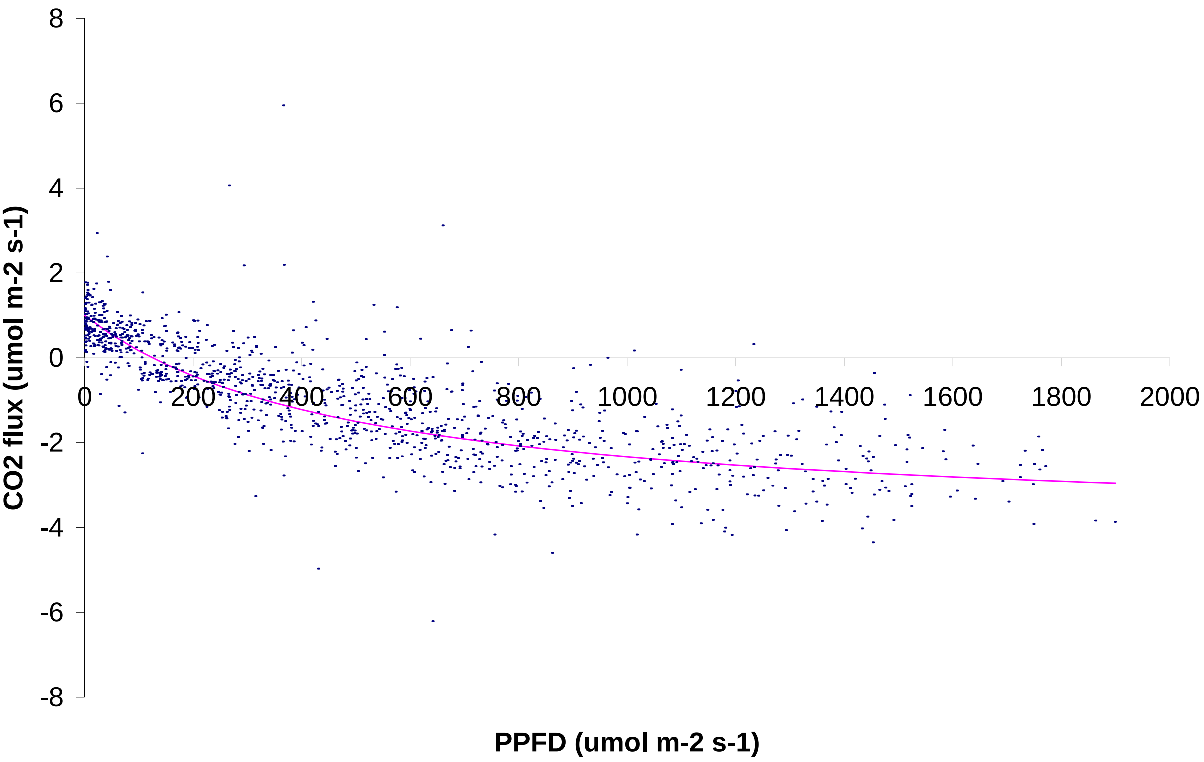

Figure 11-3 Scatter plot of CO_2 flux versus photosynthetic photon flux density, showing the 'light' response curve. Points are the mean over fifteen-minute intervals for the period 25 June to 20 July 2004, filtered to remove spikes and outliers. The curve shows Equation 11-2 fitted to the data. All Figures use the micrometeorological sign convention, whereby positive represents an emission and negative represents uptake at the surface.

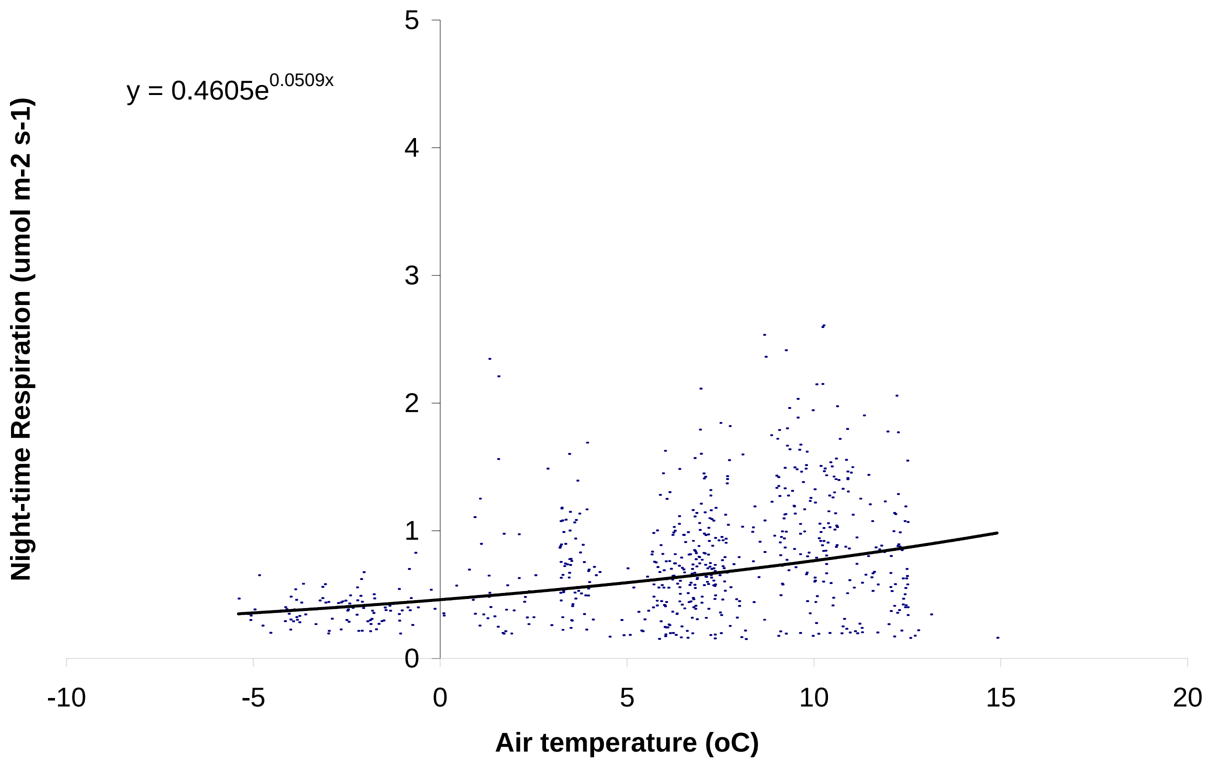

Figure 11-4 Scatter plot of the night-time CO_2 flux versus air temperature. Points are the mean over fifteen-minute intervals, for the whole of the 2004 data set, with several spikes removed. The curve shows Equation 11-3 fitted to the data.

Figure 11-4 shows the response of the night-time CO_2 flux (ie. ecosystem respiration) to temperature. There is much more scatter in this relationship, partly because the temperature range is not very large, seasonal variability is included here, and the low windspeeds at night make the eddy covariance technique less reliable. However, a general increase with temperature is discernible, and fitting the exponential model to the data is not unreasonable. This gives a fitted 'Q_{10}' value of 1.66.

Figure 11-5 shows a the observed CO_2 flux together with estimates from the gap-filling model. This shows that the gap-filling model accounts for much of the variation in the measurements, although there are always a number of outlying data points which have to be assessed and judged to be errors or not. Figure 11-6 shows the provisional cumulative CO_2 flux for the ~one-year period (18 June 2004 to 13 June 2005), based on the eddy covariance measurements where available and using the gap filling model elsewhere. This gives an annual net flux to be a small source of carbon, of 19 g C m^{-2}. This would suggest that the peat is degrading, and such that the losses from decomposition are greater than the gains from annual photosynthesis.

We emphasise that these results are provisional, and that all data will be re-processed offline. Also, the gap-filling procedure here is imperfect because of missing weather data. Substitute data for this has not yet been released by the ECN, so for some periods, a flux of zero is assumed. Furthermore, data coverage was particularly poor during the first four months of 2005, because of a run of instrument failures and lack of site access because of snow. Given a further year's data, together with the measurements of the other components of the carbon balance, a much improved estimate of the annual carbon balance will be available in the near future.

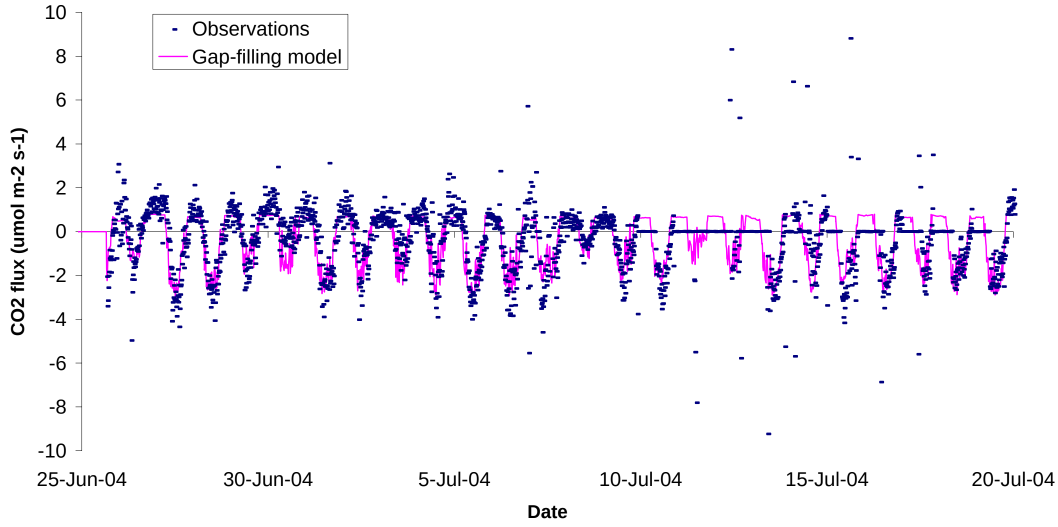

Figure 11-5 Comparison of observed CO_2 flux with gap-filling model estimates for the period 25 June to 20 July 2004.

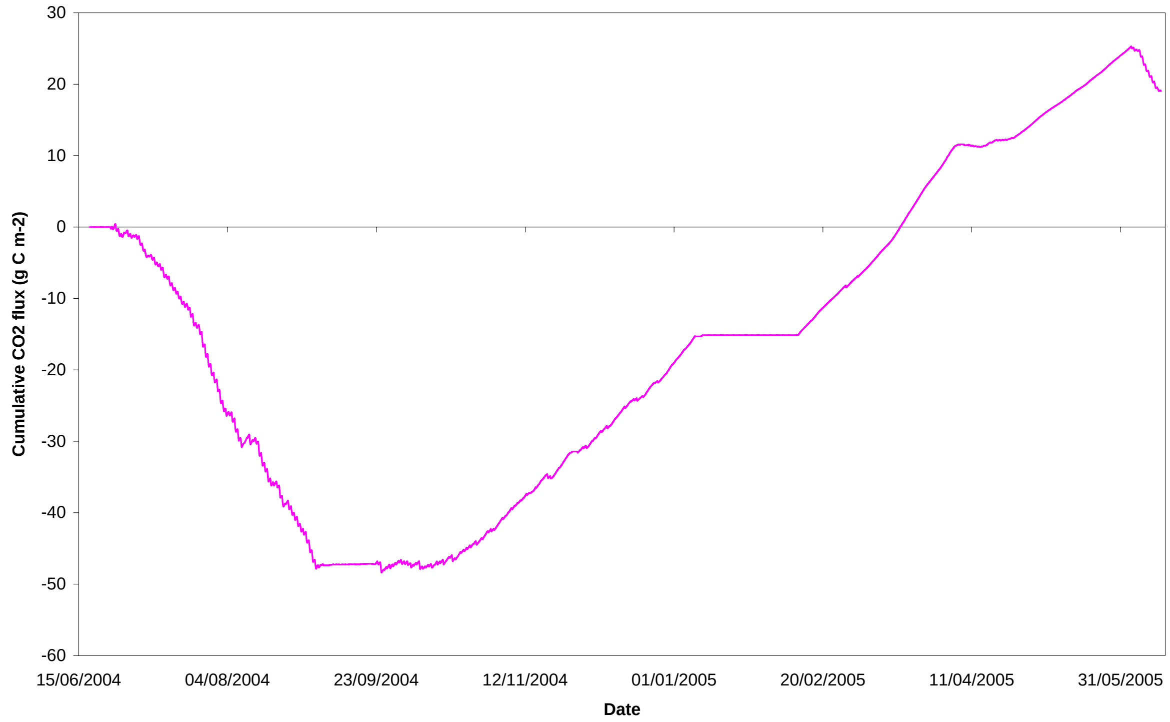

Figure 11-6 Cumulative CO_2 flux over the period 18 June 2004 to 13 June 2005, based on the eddy covariance measurements, with gap filling where necessary.

11.4. References

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11.5. Acknowledgements

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